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PHYSICAL MODEL STUDY OF A BARGE MOORING SYSTEM(U) NAVAL
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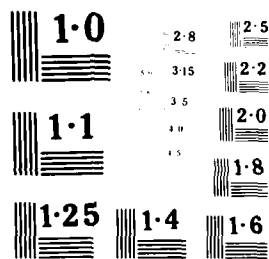
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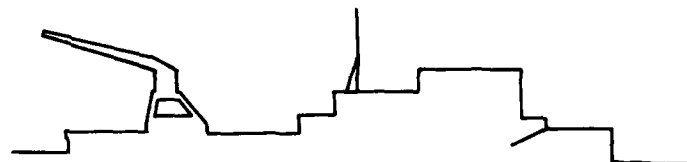
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Ocean Engineering

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PHYSICAL MODEL STUDY OF A
BARGE MOORING SYSTEM

by

ARCTEC, Inc.

William N. Seelig
CHESNAVFACENGCOM EIC

FPO-1-84(8)
April 1984

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CHESAPEAKE DIVISION
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Test results show that peak dynamic loads are produced when the driving waves force the barge/mooring system into the first mode of oscillation. In this mode of oscillation the barge behaves as a mass and the mooring behaves as a spring. Wave groups seem to drive this long period oscillation, which has periods ranging from one to several minutes.

The attached figure includes the peak mooring load data and a design curve developed by forming an upper envelope over the test results. Hindcast wind speeds required to develop various wave heights are shown on the upper portion of the figure.

EXECUTIVE SUMMARY

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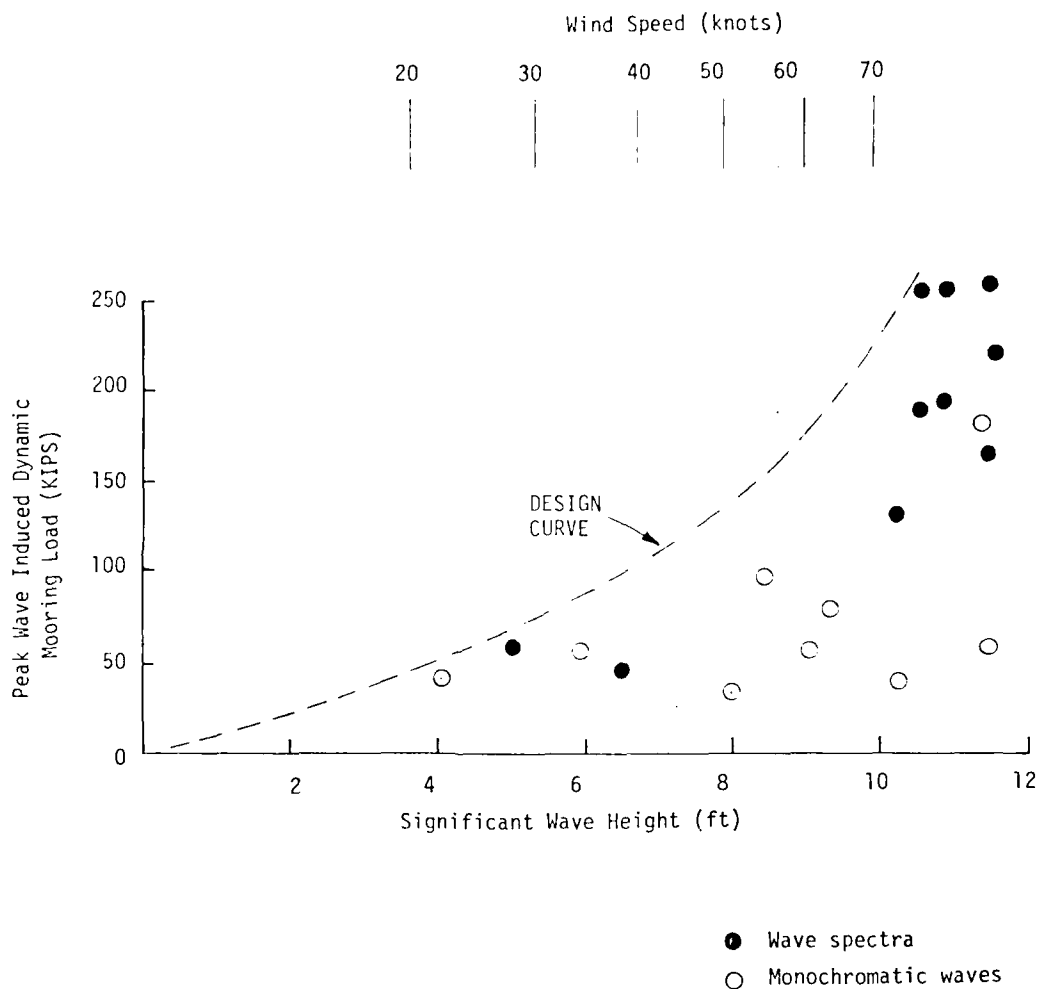
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ARCTEC, Incorporated

Report No. 1019C

PHYSICAL MODEL STUDY OF A
BARGE MOORING SYSTEM

March 1984

by

William G. Grosskopf

Submitted to

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1. INTRODUCTION

This report summarizes the physical modeling of a barge and mooring system in shallow water wave conditions to evaluate wave forces that will occur on the structure. A barge and mooring system, conceptually designed by the Chesapeake Division of the Naval Facilities Engineering Command, was modeled at a scale of 1:28 and tested in a wave tank at ARCTEC, Incorporated in Columbia, Maryland. The model was subjected to a variety of regular and random wave conditions with mooring line tension data collected via an HP 2240A Measurement and Control Processor and an HP 9816 microcomputer system. The data was then analyzed by the HP 9816 computer to provide zero up-crossing statistics, cumulative distribution functions and spectral analyses. Video recording of each test were also acquired to document the motions of the barge under the various incident wave conditions.

2. TESTING CONDITIONS

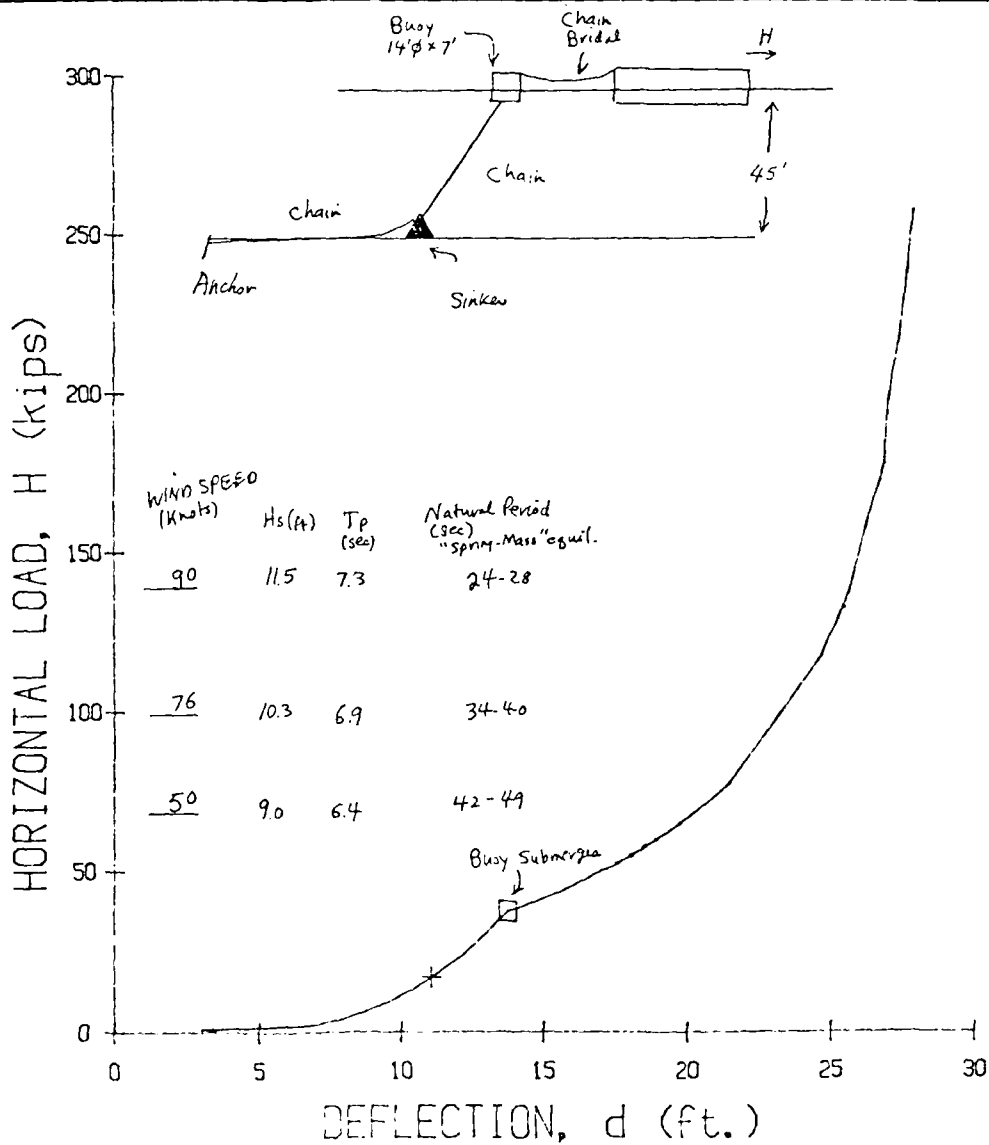
The conceptual design of the barge and mooring system is shown as provided by NAVFAC in Figure 2.1. The barge is moored to a large buoy by a chain bridle. The buoy is moored to a heavy sinker which sits on the sea bottom and is in turn moored to an anchor that also resides on the seafloor. The design water depth is 45 feet.

Also provided by NAVFAC was a load-deflection curve for the prototype mooring system which is also presented in Figure 2.1. The curve was developed for the horizontal static loads expected on the system due to wind and current. It is assumed in this study that measured wave forces will linearly superimpose on these static forces.

A wave hindcast was performed by NAVFAC to develop expected wave conditions at the planned prototype site of the structure. This hindcast yielded four wave conditions to be examined in this test program:

TEST CONDITION DESIGNATION	RETURN INTERVAL (YRS)	WIND SPEED (KNOTS)	STATIC FORCE (KIPS)	SIGNIFICANT WAVE HEIGHT (FT)	PEAK WAVE PERIOD (SEC)
A	-	30	26.5	5.3	5.0
B	1	60	69.0	9.0	6.4
C	10	76	102.0	10.3	6.9
D	25	90	139.0	11.5	7.3

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3. MODEL CRITERIA

Based on the above-mentioned test conditions, a two-dimensional model study of the system in waves was requested by NAVFAC. A Froude model at a scale of 1:28 was specified, with model testing in both regular and random waves. The barge model to be used for the test was provided by NAVFAC. This model in prototype measures 105 feet wide by 120 feet long and scaled to 114 cm wide by 131 cm long for testing.

The wave conditions given above were tested in both monochromatic and irregular modes, with the irregular seas specified using the required wave heights as significant wave heights and the wave periods as the peak periods of the wave spectrum. The form of the wave spectrum used was that found typical of shallow water random seas, and is described in the next section. The four wave height-period combinations, given in Section 2, and two sea types (random and regular) were included in a range of 23 tests to study the wave forces experienced by the barge-mooring system.

The mooring, a single point configuration for this test program, was modeled using a series of springs to simulate the nonlinearity of the load-deflection curve. The spring constants were specified to provide the proper total deflection of the system at any given total load. After the desired springs arrived at the laboratory, the springs were "broken in" by applying a cyclical load to the spring. Following the "breaking in" period, the spring constants were re-measured in order to redefine the required extension limits for each spring. The spring constants were as follows for the four-spring system.

<u>Spring</u>	<u>Specified Spring Constant (lb/cm)</u>	<u>Spring Constant After Break-In (lb/cm)</u>
1	0.11	0.115
2	0.39	0.385
3	0.79	0.764
4	2.28	2.284

The range of load for each best-fit line segment of the load deflection curve was chosen as:

<u>Line Segment</u>	<u>Full Scale Load (kips)</u>		<u>Model Scale Load (lbs)</u>	
	<u>Minimum</u>	<u>Maximum</u>	<u>Minimum</u>	<u>Maximum</u>
1	0	22	0	1.00
2	22	72	1.00	3.28
3	72	150	3.28	6.83
4	150	270	6.83	12.30

Using these load ranges for each line segment, the deflection of these spring systems for each line segment and the total deflection of each spring is specified:

Spring	EXTENSION (cm)				Total Spring Extension
	1	2	3	4	
1	8.47	-	-	-	8.47
2	2.54	5.77	-	-	8.31
3	1.27	2.88	4.50	-	8.65
4	0.44	0.99	1.55	2.41	5.39

System Deflection:

Model Scale (cm)	12.72	9.64	6.05	2.41
Full Scale (ft)	11.68	8.86	5.56	2.21

The mooring system was varied in configuration for each wave condition examined, in order to bring the mooring system to the correct point on the static load-deflection curve before the waves were run. This precaution was chosen to eliminate the need to actually apply a static force to the model during testing. Figure 3.1 shows the load-deflection curve simulated by the four-spring system, and the static loads expected to be concurrently felt by the structure during the four wave conditions. Test Condition 1, the 30-knot wind speed case, falls very low on Segment 2; Test Condition 2, the 60-knot wind speed case, falls very low on Segment 3; Test Condition 3, the 76-knot case, falls midway along Segment 3; and Test Condition 4, the 90-knot case falls very close to the low point of Segment 4. Therefore, a matrix results with the springs and spring extensions as shown in Table 3.1 for each test.

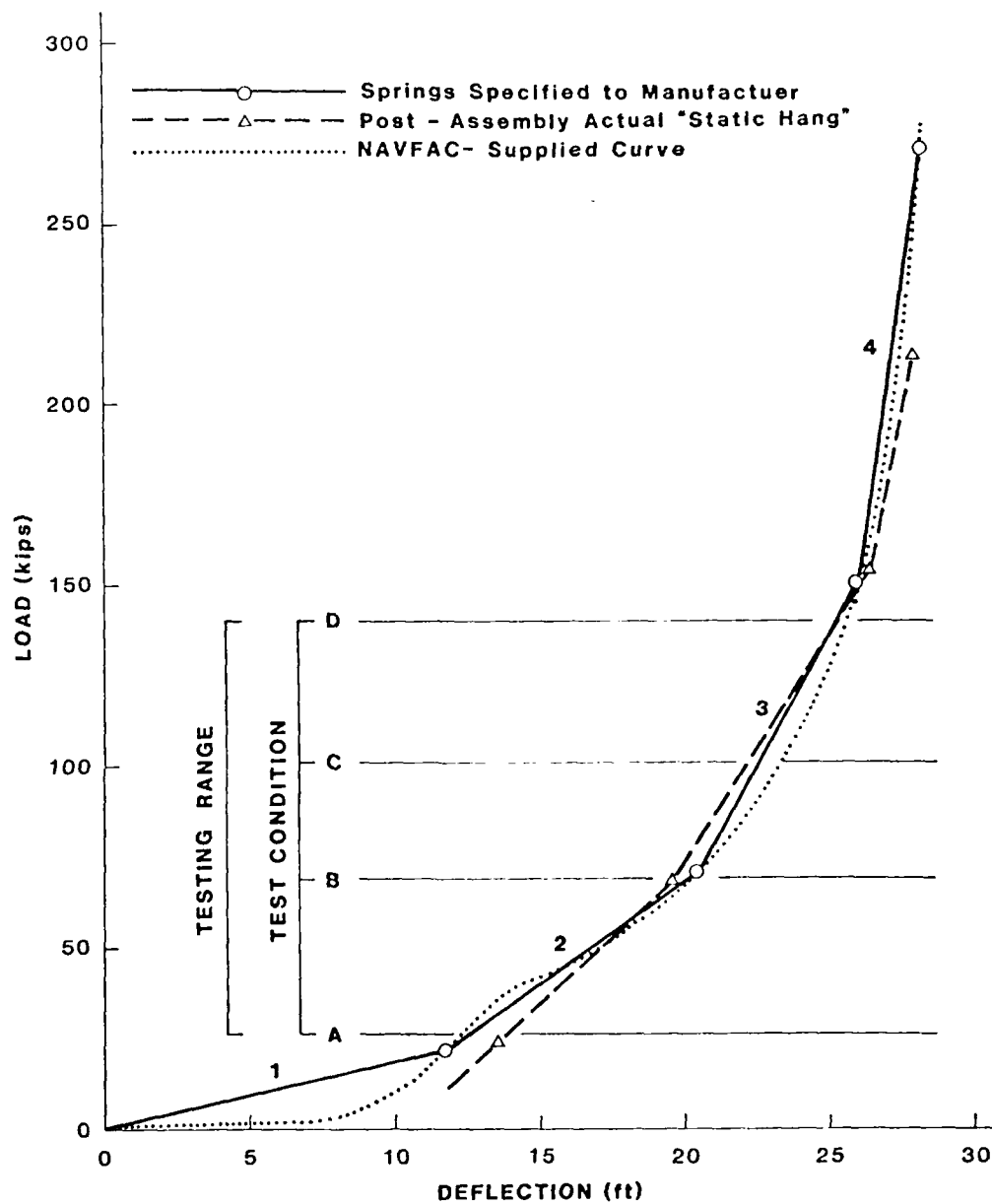


FIGURE 3.1
LOAD-DEFLECTION OF MODELED MOORING IN PROTOTYPE UNITS

TABLE 3.1
TEST MATRIX FOR NAVFAC BARGE/MOORING STUDY

Test Number	Wave Condition*	Prototype		Model Scale		Mooring Spring Extensions (cm)			
		Height (ft)	Period (sec)	Height (cm)	Period (sec)	1	2	3	4
1	Regular	5.3	5.0	5.8	0.95	Leave out of System	8.31	8.66	No Limit
2	Random	5.3	5.0	5.8	0.95		8.31	8.66	
3	Regular	9.0	6.4	9.8	1.21		Leave Out of System	2.21	
4	Random	9.0	6.4	9.8	1.21			2.21	
5	Regular	10.3	6.9	11.2	1.30			Leave Out of System	
6	Random	10.3	6.9	11.2	1.30				
7	Regular	11.5	7.3	12.5	1.37				
8	Random	11.5	7.3	12.5	1.37				

* Random wave conditions were generated with the significant height and peak wave period corresponding to that reported here.

4. TEST BASIN CONFIGURATION

The tests were performed in ARCTEC's Coastal Wave Tank facility, which is 100 feet long, 12 feet wide and up to 10 feet deep. The waves are generated by a hydraulically-driven piston-type wavemaker. The wavemaker signals were calculated by an APPLE II Plus computer system which superimposes up to 50 sinusoidal wave components and updates the wavemaker position every 0.01 seconds. Bales of stainless steel turnings were placed along the far end of the tank to effectively dissipate wave energy with a minimum of reflection.

Two wave probes and one tension link were used to collect data in the tests. The wave probes were capacitance type and positioned two feet apart in front of the barge model to facilitate wave reflection analysis and to provide duplication of wave measurement. The tension link was a strain gage-type of sensor installed in the mooring line. All data was collected at a rate of 16 Hz by the HP 9816S computer system. Video was also taken of each test. Figure 4.1 illustrates the basin configuration for the tests.

Random wave conditions were generated by first numerically deriving a shallow water wave spectrum parameterized in shape according to recent studies of shallow water spectral forms (Vincent, 1981). Each spectrum was sliced into frequency segments all of equal area which were converted to monochromatic wave components. The components had a period corresponding to the central frequency of the area slice and a height which provided the proper amount of energy to the water surface. These components were recorded on floppy disk. During a test run, the computer randomly assigned each component a phase angle and then superimposed all the components on a real time basis every 0.01 seconds.

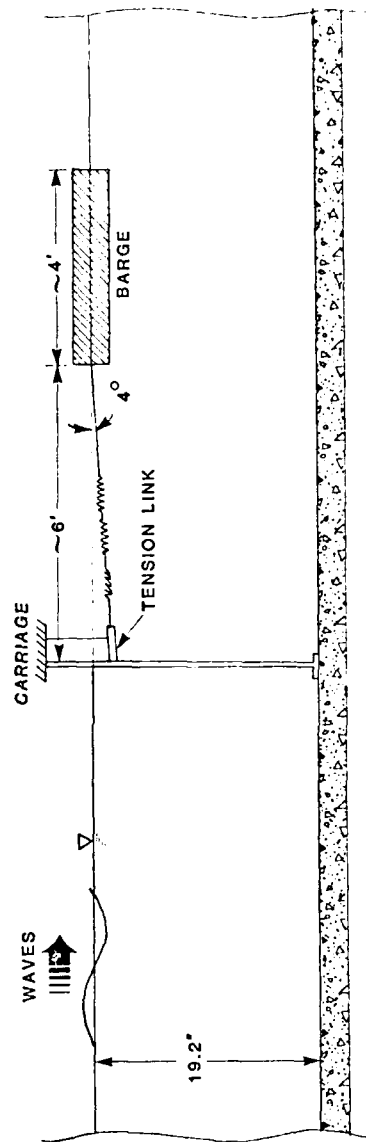
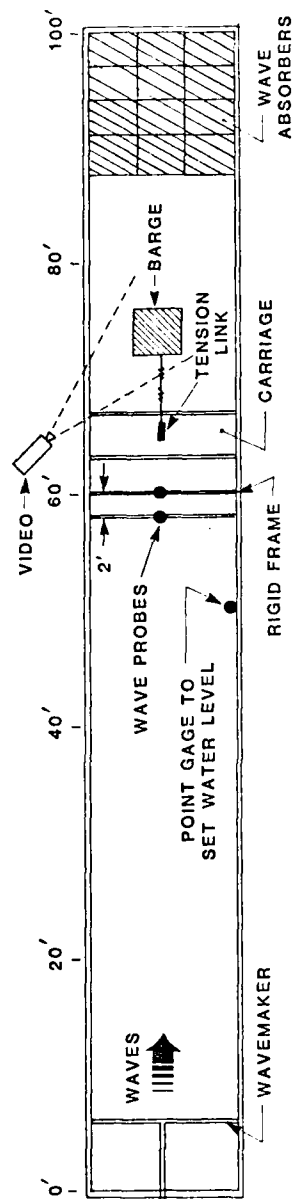


FIGURE 4.1 SCHEMATIC OF WAVE BASIN AND TESTING CONFIGURATION

5. DATA ANALYSIS PROCEDURES

The data collected included:

- Mooring Tension Measurements
- Wave Measurements
- Video Tape Recordings

The tension and wave records were written digitally to HP 9816S microdisks along with zeroes and calibration constants for each test. The following analyses were performed on the data:

- Time Series Plot
- Zero-Upcrossing
- Fast-Fourier Transform
- Cumulative Distribution Function

All the results of the analyses are shown in Section 6.

Zero-Upcrossing Analysis

A zero-upcrossing analysis was performed on the digital data to provide:

- Mean Crest-To-Trough Height
- RMS Height
- Significant Height (Average of Highest One-Third)
- Largest Crest-To-Trough Height
- Period Of The Significant Height
- Mean Period
- Number of Waves
- Crest Height/Crest-To-Trough Height
- Height Of Wave Crest/Period Of Entire Wave

Initially, the mean of the time series was calculated and subtracted from every data point. The RMS Height was then found by:

$$\text{RMS Height} = 4 \left(\sum_{i=1}^N H^2(i) \right)^{1/2}$$

The Significant Height, H_{sig} , was determined by averaging the highest one-third zero-upcrossing wave heights and the period of the significant height, T_{sig} , was found by averaging the period associated with those waves included in the calculation of H_{sig} .

Fast Fourier Transform

The time series was then passed through an FFT routine to indicate peak response frequencies of the mooring tension and wave channels. The resulting energy spectra are plotted in energy-density or "force-density" units. Normally a total of 4096 data points were processed at 16 Hz and plotted after band-averaging eight spectral lines. The resulting band width was 0.03125 Hz. Phase spectra were also presented on a line-by-line basis.

Cumulative Distribution Function

The trough-to-crest wave heights (or zero-to-peak force heights) were ranked and plotted on a normal probability plot. This data should give some indication of the form of the distribution of wave-induced mooring forces.

6. TIME SERIES AND ANALYSES

Twenty-three tests were run to provide NAVFAC with more of a range of wave conditions and force data to analyze the forces on the barge. This range of wave conditions encompassed the targeted wave conditions originally outlined by NAVFAC and shown in Table 3.1. The actual tests that were performed are listed below. The detailed data and analysis results follow.

TEST	MAXIMUM FORCE (N)	WAVE CONDITION		TEST LENGTH	WAVE TYPE
		HT (CM)	PER (S)**		
1	11.3	10.0	0.93	60 sec	Regular
2	8.0	4.5	0.87	60 sec	Regular
3	18.5	9.3	0.92	60 sec	Regular
4	11.8	12.5	0.91	60 sec	Regular
5	8.4	7.2	0.85	120 sec	Random
6	11.2	5.5	0.85	120 sec	Random
7	7.5	11.2	1.17	60 sec	Regular
8	3.4	6.5	1.17	60 sec	Regular
9	5.8	8.9	1.17	60 sec	Regular
10	25.1	11.3	1.06	120 sec	Random
11	21.7	14.6	1.26	60 sec	Regular
12	11.2	17.9	1.25	60 sec	Regular
13	31.1	19.1	1.26	60 sec	Regular
14	39.0	11.7	1.18	120 sec	Random
14a	39.0	11.6	1.24	300 sec	Random
15	50.8	11.6	1.27	120 sec	Random
15a	50.8	11.8	1.27	300 sec	Random
16	36.0	12.1	1.33	120 sec	Regular
17	15.1	10.1	1.33	120 sec	Regular
18	42.8	14.2	1.33	120 sec	Regular
19	37.5	12.4	1.31	120 sec	Random
19a	52.1	12.7	1.30	300 sec	Random
20	32.5	12.5	1.31	120 sec	Random
20a	44.0	12.7	1.31	300 sec	Random
21	32.4	16.6	1.45	120 sec	Regular
22	34.0	19.0	1.45	120 sec	Regular
23	31.0	14.8	1.69	120 sec	Regular

* If an unusually large first wave occurred in a test, it was disregarded.

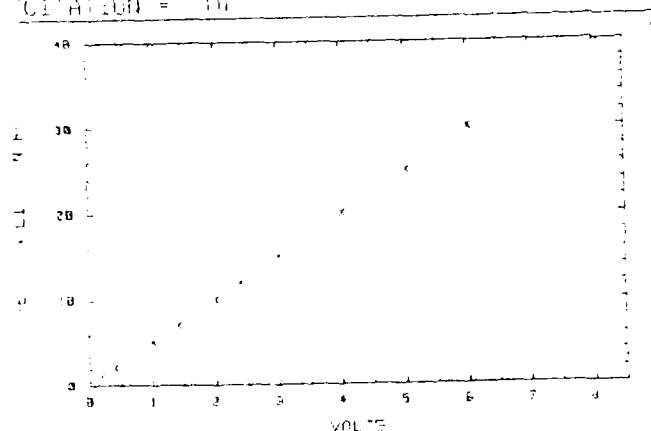
** Random wave peak periods appear slightly low because band averaging over 0.05 Hz was used in analysis. Consequently, the period of highest significant energy in the band of peak energy is $INV [0.05 + 1/T_5]$.

6. TIME SERIES AND ANALYSIS PLOTS

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4	+5.0000E+00	1010
5	+7.0000E+00	1410
6	+1.0000E+01	2017
7	+1.2000E+01	2402
8	+1.5000E+01	3001
9	+2.0000E+01	4034
10	+3.5000E+01	5040
11	+3.0000E+01	5045
12	+4.0000E+01	6062

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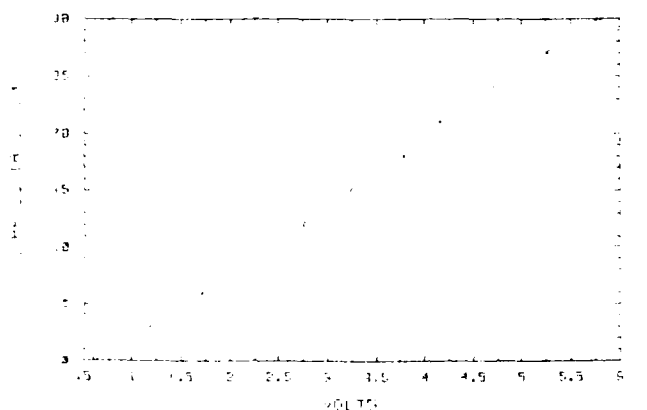
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CALIBRATION SUMMARY

WAVEFORM: 0130 DATE: MAR 19, 1984
TIME: 14:25:54

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5	+1.2000E+01	2747
6	+1.5000E+01	3252
7	+1.8000E+01	3752
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11	+3.0000E+01	5790

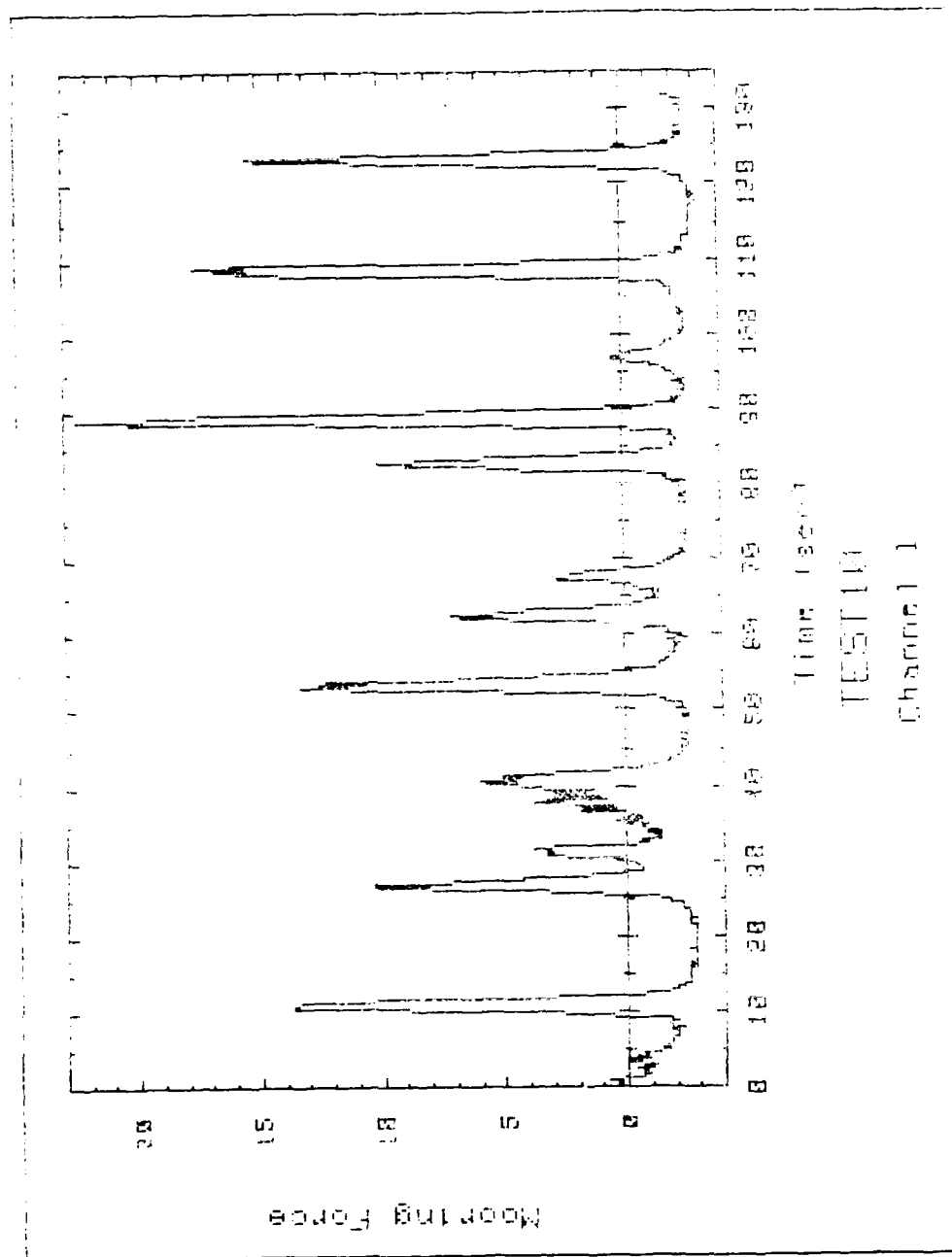
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 XIN = 2
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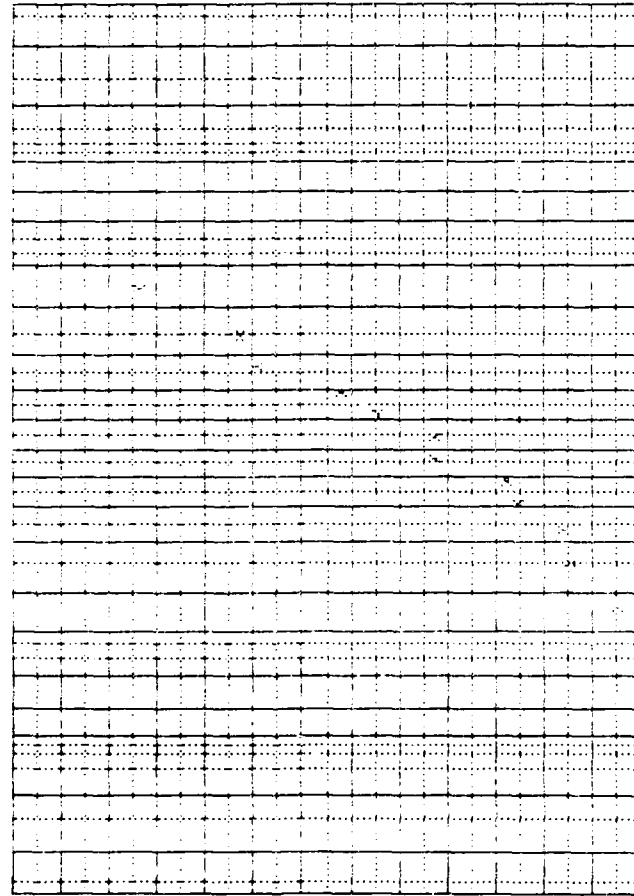
CALIBRATION SUMMARY

APPENDIX - COMPUTER OUTPUT FOR A
SAMPLE RUN (TEST 10)



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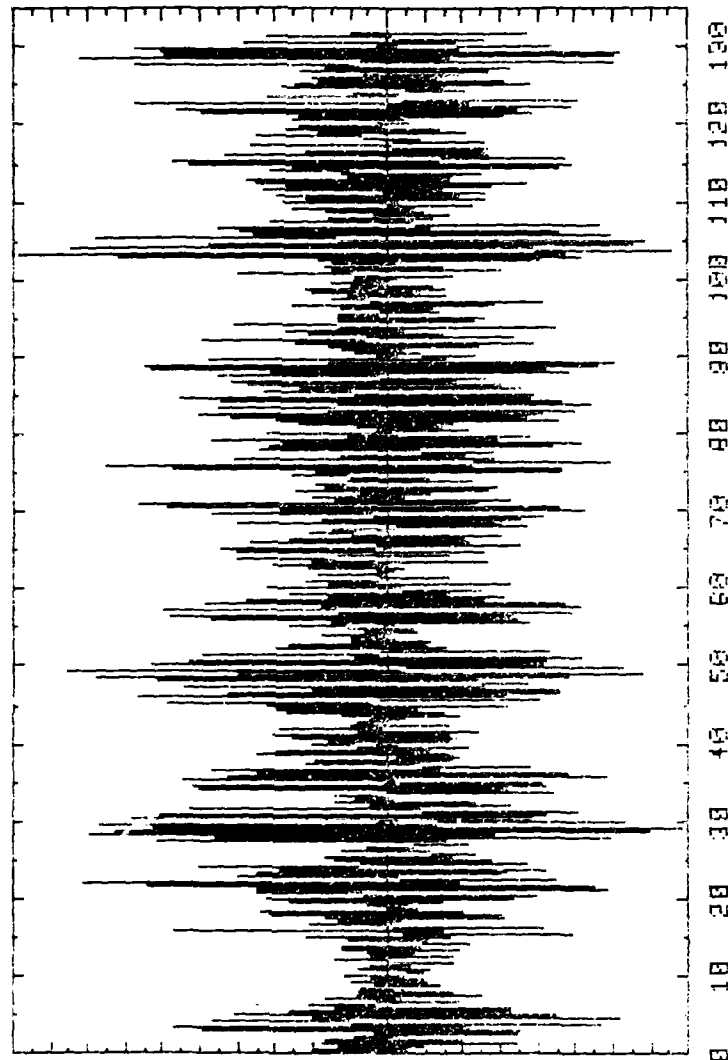


Cumulative Distribution Function (%)

TEST 10

Channel 1

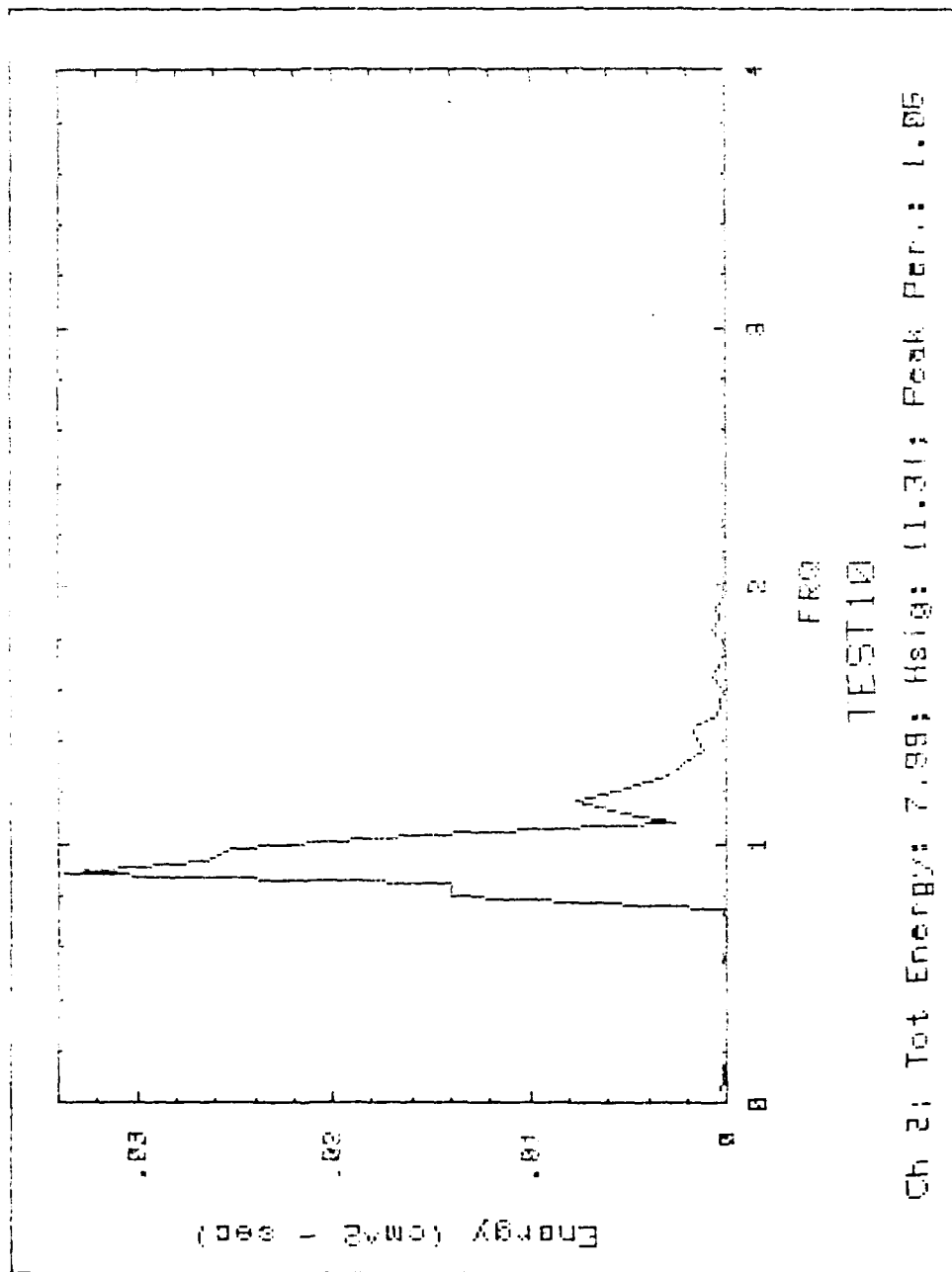
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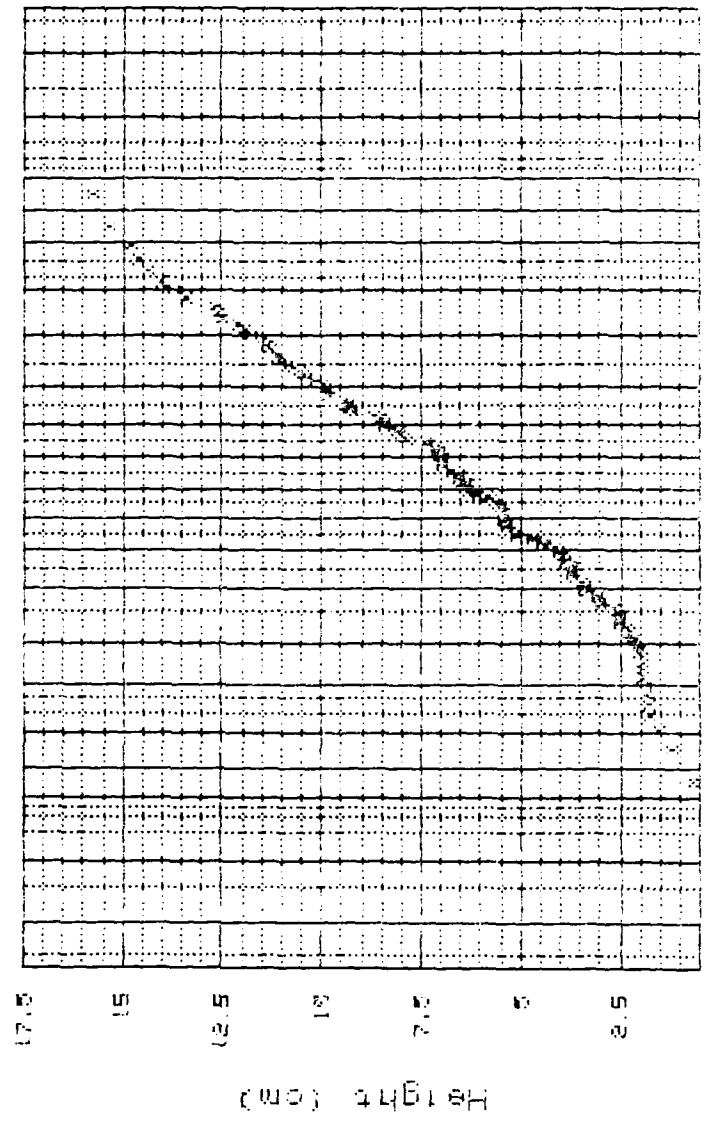


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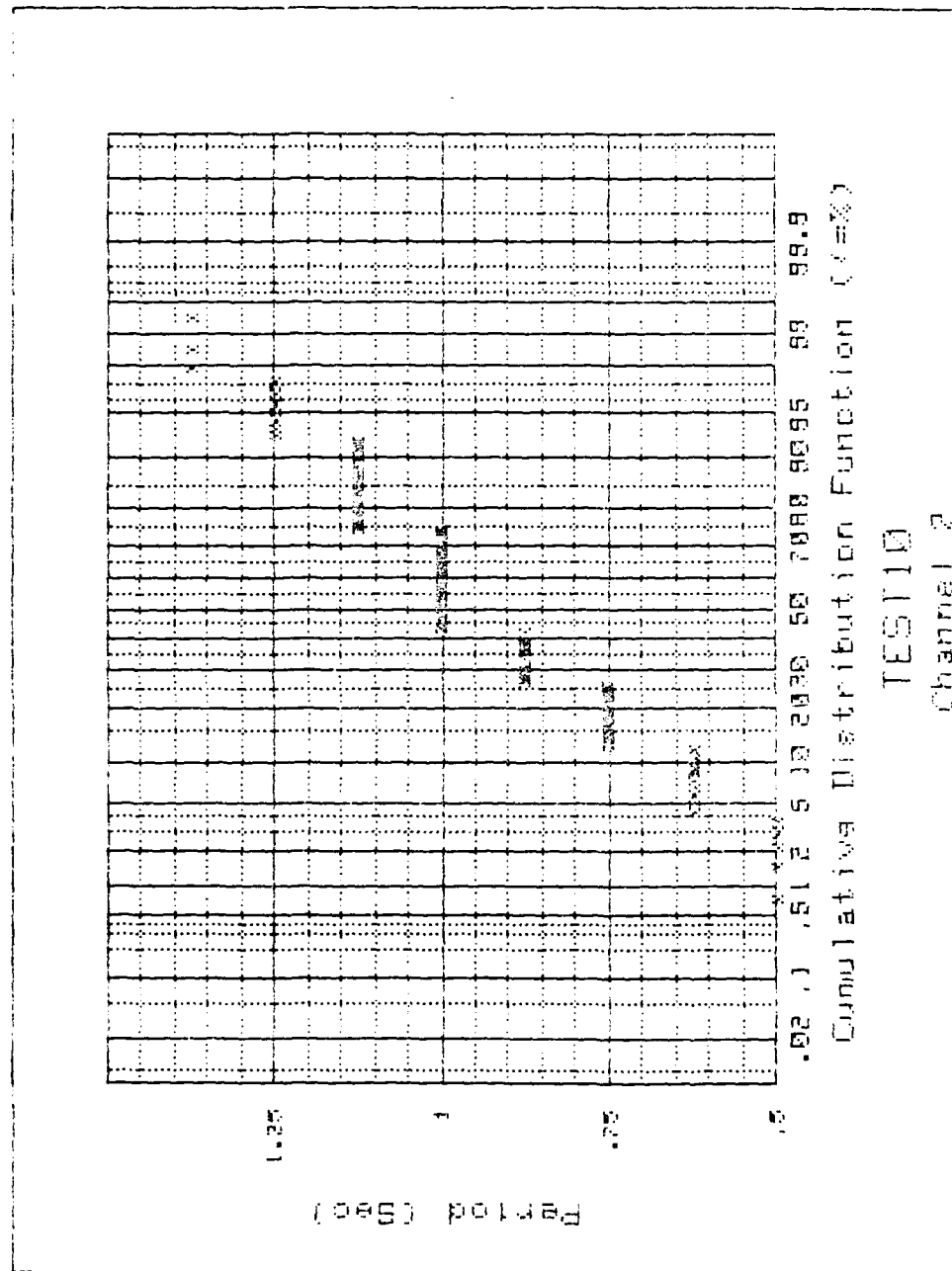
TEST 10

Channel 3





TEST10
Channel 2



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